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STUDIES ON THE SWELLING OF FOODS
I. ON THE DETERMINATION OF THE SWELLING VELOSITY OF RICE

By

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In spite of the fact that there is a relation between the swelling of foods and the manufacture, preparation and/or deterioration of them, the phenomenon itself has been left in the dark, because these phenomena have chiefly been studied as physicochemical subjects. Thus, most of these subjects have been studied with simple samples as starch (1—3), gelatin (4—6), and agar-agar (3).

A few studies have been reported on complicated samples as cereals (7—8) or tangle (9), but many problems still remain unsettled. Recently, rheological behaviours about starchs and protains are actively being investigated in connection with the food manufacturing. But, at the same time, it is very important to settle the pending questions about the swelling itself, because this phenomenon is the first stage in the manufacture of foodstuffs.

The swelling is not so clear in its theoretical explanation, but usually, they are grouped as follows:

(1) Intermicellar swelling; water molecules are adsorbed on the surface of micelles and in crevices among them, and there is no transformation of the number, position and strength of the Laue's photograph.

(2) Intramicellar swelling; water molecules enter into micelles, and hydration or chemical changes take place.

MORRISON and HALDEN (10) have studied on the swelling of wool keratin, and recognised three groups, i.e., intermicellar swelling, intramicellar swelling and hydrogen bond.

When any substances swell, as is shown in either case, some combination between micelles and water molecules will take place, so it may be certain that concentration of water molecules in the adsorbing layer and transition of micelles take place, and the total of the volume of water and that of xerogel must decrease.

Therefore, the swelling itself can be observed by measuring the decrease of total volume. This method may be most suitable for determining the swelling velocity, especially when studying on cereals. KATZ and TAFFEL (5) reported that between the decrease of total volume and the weight of absorbed water some simple relation will be observed as shown in Fig. 1.

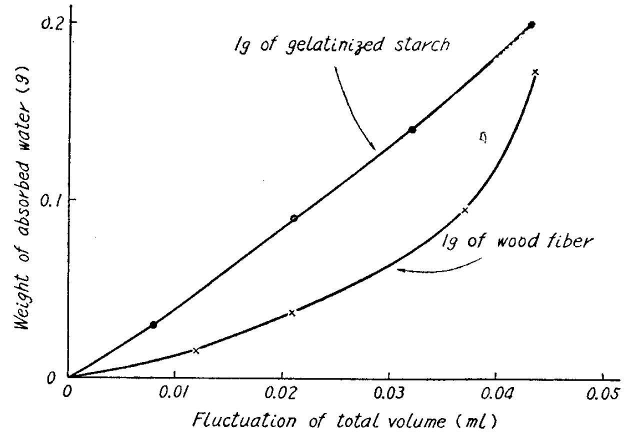

Fig. 1. The relation between the decrease of total volume and the weight of absorbed water.

The swelling velocity of rice which has been measured by this method by the authors will be reported in this paper.

Materials and Methods

1. Materials

The samples of rice which was determined by the authors and their humidity (dried in atmosphare at 105°C) were as follows:

polished non-glutinous rationed rice	16.2%
polished glutinous rationed rice	16.4%
unpolished non-glutinous rice which is named "SASA SIGURE"	16.0%
polished non-glutinous rice, "SASASIGURE" (polish rate 6%)	15.4%
unpolished glutinous rice which is named "MIYAKOGA NE-MOTI"	15.4%

Pure water which have been deionised with ion exchange resin was used to swell them.

2. Method

The apparatus which is shown in Fig. 2 was designed to measure the total volume decrease.

Experimental

Two stopcocks B and D were fixed with ground glass joints to the separated necks of flask A whose capacity is about 370 *ml*, containing the necessary quantity of rice. The graduated measuring tube C, whose diameter is 2 mm, is fixed to the center neck. Pure water was poured into the water vessel E, and then the whole apparatus was settled in a thermostat whose temperature has been adjusted at 20.0±0.2°C, and left in it for 15hr. When the sample, pure water and apparatus were stabilized to the designated temperature, the stopcock B and D were opened to lead water into the apparatus by forcing air through the glass tube G, and the apparatus was filled up with water.

Since the sample and water were mixed, the water surface in the measuring tube C was observed at suitable intervals.

As it was easily assumed that the swelling velocity may be disturbed by the air kept in the inner part of samples, and sometimes the measurement may be disturbed by foams of air made by the retreating water, another method was taken up for measurement which is as follws.

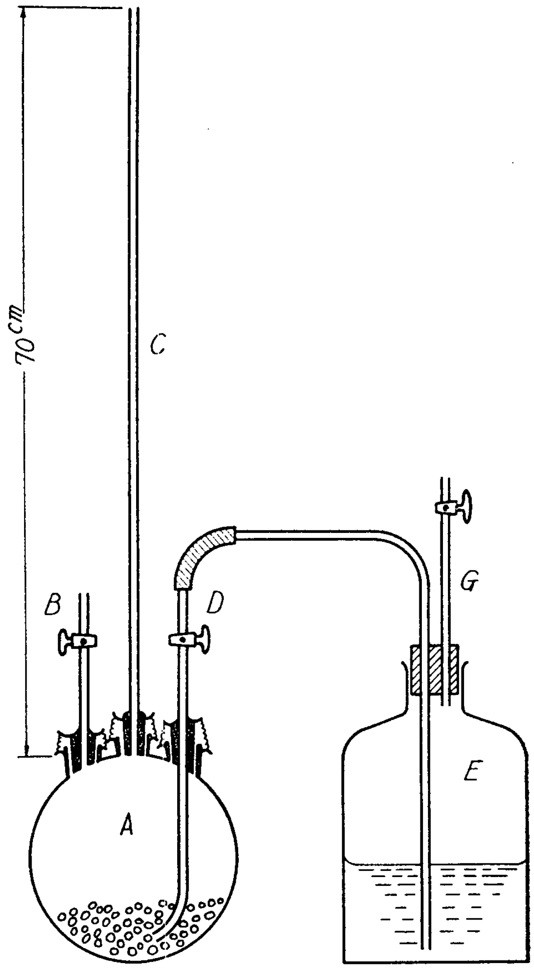

Fig. 2. The apparatus for the measurement of the total volume decrease.

Before the sample and water are mixed, the top of the measuring tube and the tube G are connected with a vacuum pump, and the inner part of the apparatus and the sample are kept at low pressure, about 10 mmHg for one hour. Then, the stopcock of the vacuum pump is closed, and the stopcock D is opened to lead water into the measuring vessel.

After these treatments, the vacuum pump is taken off and measurement is begun.

Result

The observed values which were measured with 150 g of polished non-glutinous rice and 230 *ml* of pure water are shown in Table 1 and Fig. 3.

In this measuring method, it can not be decided, when water comes into contact with the object without interference of the outside air. So, these values are expressed in a way in which the fluctuation of the total volumes at 3 hr after starting of measurements are 0.00 *ml*.

Samples and water are not perfectly the same in their ratio, but this may have no influence on the observed values, because considerably excessive water is used.

The observed values reappeared just as shown in this table, but all measurements were done twice at least, and averaged. In the tables and the figures following Table 2 and Fig. 3, all of the observed values are shown.

Discussion

The relation between the decrease of total volume and the quantity of absorbed water is as aforesaid;

$$V = \frac{AW}{B + W}$$

V is total volume decrease
W is quantity of absorbed water
A and B are constants

On the swelling velocity of all kinds, the following empirical formula has been known;

$$\frac{dW}{dt} = k(W_m - W)$$

t is time after the starting of swelling
W is absorbed water at time t
W_m is saturated value of absorbed water at maximum time
k is constant

If the total volume decreases, the curve must appear as a simple curve in accordance with these formulas, but the observed values go beyond this knowledge. In spite of the expectation that the total volume shall decrease only after swelling has started, it keeps on increasing for 18 min, and then reverts to the volume at the starting time, and then a smooth curve follows. This abnormal phenomenon is so remarkable and certain, that its cause must not be attributable to uncertainty of measurements.

Since the principle of swelling shows that the total volume must decrease

Table 1. The increase and decrease of the total volume of the polished non-glutinous rice (rationed) and water, before they were exhausted.
150g of rice and 230 *ml* of water

Time	Fluctuation of total volume			Time	Fluctuation of total volume		
	1st experiment	2nd experiment	Average		1st experiment	2nd experiment	Average
7 min	1.35 *ml*			1hr 00 min	0.53 *ml*	0.52 *ml*	0.53 *ml*
8	1.48			2	0.49	0.48	0.49
9	1.59			4	0.45	0.44	0.45
10	1.69	1.64 *ml*	1.67 *ml*	6	0.41	0.40	0.41
12	1.86	1.74	1.80	8	0.38	0.36	0.37
14	1.95	1.88	1.92	10	0.35	0.33	0.34
16	2.02	1.96	1.99	12	0.32	0.30	0.31
18	2.03	2.00	2.02	14	0.29	0.27	0.28
20	2.00	2.00	2.00	16	0.27	0.25	0.26
22	1.95	1.96	1.96	18	0.25	0.23	0.24
24	1.89	1.90	1.90	20	0.24	0.22	0.23
26	1.81	1.83	1.82	22	0.22	0.20	0.21
28	1.72	1.75	1.74	24	0.20	0.18	0.19
30	1.61	1.66	1.64	26	0.19	0.17	0.18
32	1.53	1.57	1.55	28	0.18	0.16	0.17
34	1.43	1.48	1.46	30	0.17	0.15	0.16
36	1.35	1.39	1.37	35	0.14	0.13	0.14
38	1.25	1.30	1.28	40	0.12	0.10	0.11
40	1.18	1.20	1.19	45	0.11	0.09	0.10
42	1.10	1.11	1.11	50	0.08	0.06	0.07
44	1.02	1.03	1.03	55	0.07	0.05	0.06
46	0.95	0.95	0.95	2hr 00 min	0.05	0.04	0.05
48	0.87	0.88	0.88	30	0.03	0.00	0.02
50	0.81	0.80	0.81				
52	0.75	0.74	0.75	3hr 00 min	0.00	0.00	0.00
54	0.69	0.68	0.69	30	−0.03	−0.03	−0.03
56	0.63	0.62	0.63				
58	0.58	0.57	0.58				

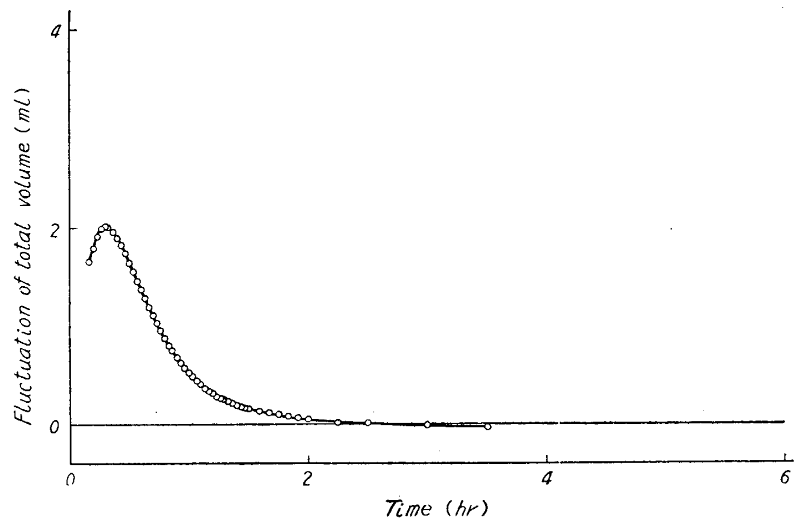

Fig. 3. The velocity curve of the fluctuation of total volume of the polished non-glutinous rice (rationed) and water.

Table 2. The fluctuation of the total volume of the polished non-glutinous rice (rationed) and water, after they were exhausted.
150 g of rice and 230 *ml* of water

Time	Fluctuation of total volume	Time	Fluctuation of total volume	Time	Fluctuation of total volume
5.5 min	0.98 *ml*	23 min	1.85 *ml*	52 min	0.87 *ml*
6	1.03	24	1.83	54	0.81
7	1.13	25	1.81	56	0.75
8	1.25	26	1.79	58	0.70
9	1.36	27	1.76		
10	1.45	28	1.73	1hr 00 min	0.64
11	1.55	29	1.71	5	0.53
12	1.63	30	1.67	10	0.43
13	1.69	32	1.62	15	0.35
14	1.74	34	1.52	20	0.29
15	1.79	36	1.45	40	0.14
16	1.82	38	1.37		
17	1.85	40	1.30	2hr 00 min	0.06
18	1.86	42	1.22		
19	1.87	44	1.15	3hr 00 min	0.00
20	1.87	46	1.07		
21	1.88	48	1.01	4hr 00 min	−0.03
22	1.86	50	0.94	40	−0.04

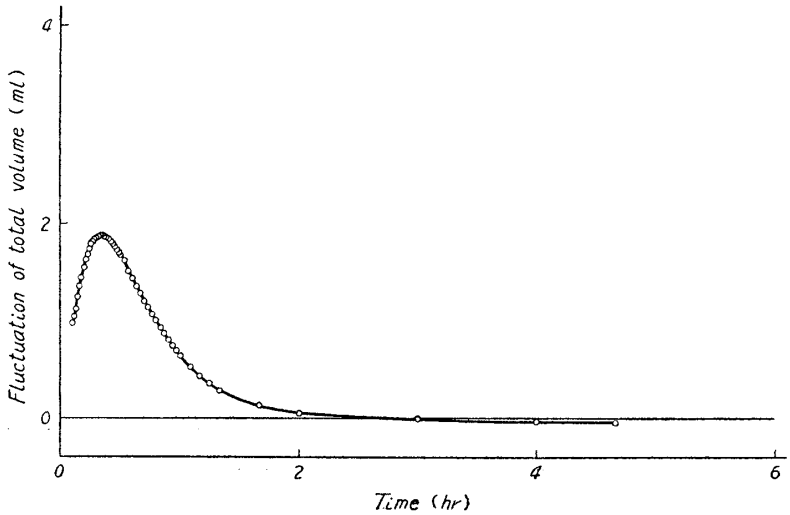

Fig. 4. The velocity curve of the fluctuation of total volume of the polished non-glutinous rice and water, after they were exhausted.

Table 3. The fluctuation of the total volume of the polished glutinous rice (rationed) and water, before they were exhausted.
150 g of rice and 240 *ml* of water

Time	Fluctuation of total volume	Time	Fluctuation of total volume	Time	Fluctuation of total volume
5 min	1.03 *ml*	30 min	3.39 *ml*	1hr 3	1.14 *ml*
5.5	1.09	31	3.33	4	1.09
6	1.17	32	3.26	5	1.05
6.5	1.25	33	3.18	6	1.01
7	1.33	34	3.11	7	0.98
7.5	1.42	35	3.03	8	0.94
8	1.52	36	2.96	9	0.90
8.5	1.62	37	2.87	10	0.87
9	1.73	38	2.78	11	0.83
9.5	1.84	39	2.71	12	0.80
10	1.95	40	2.63	13	0.77
10.5	2.06	41	2.54	14	0.74
11	2.17	42	2.46	15	0.72
11.5	2.28	43	2.39	16	0.69
12	2.39	44	2.31	17	0.67
12.5	2.49	45	2.23	18	0.65
13	2.59	46	2.15	19	0.62
13.5	2.83	47	2.08	20	0.59
14	2.92	48	2.01	25	0.50
15	3.08	49	1.94	30	0.42
16	3.23	50	1.87	35	0.36
17	3.35	51	1.80	40	0.31
18	3.45	52	1.74	45	0.27
19	3.52	53	1.68	50	0.23
20	3.58	54	1.61	55	0.20
21	3.62	55	1.56		
22	3.64	56	1.50	2hr 00 min	0.17
23	3.65	57	1.44	30	0.07
24	3.64	58	1.39		
25	3.63	59	1.34	3hr 00 min	0.00
26	3.60			30	−0.05
27	3.56	1hr 00 min	1.29		
28	3.51	1	1.23	4hr 00 min	−0.09
29	3.46	2	1.19	30	−0.13

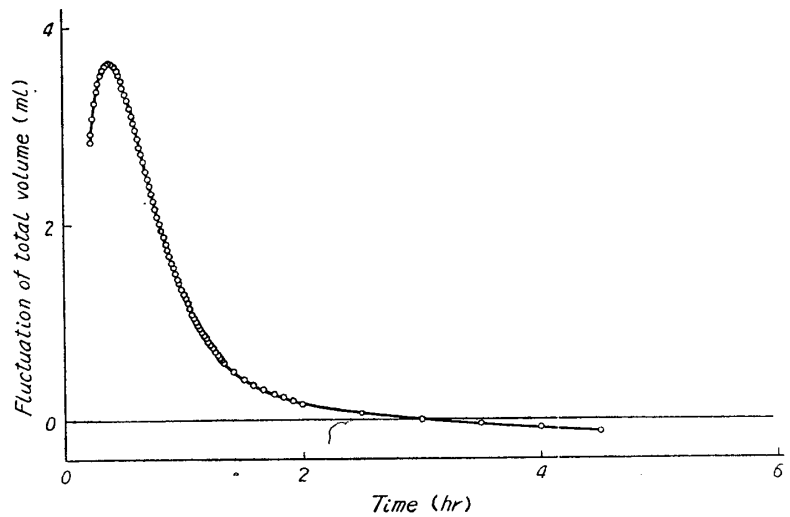

Fig. 5. The velocity curve of the fluctuation of total volume of the polished glutinous rice (rationed) and water.

Table 4. The fluctuation of the total volume of the polished glutinous rice (Rationed) and water, after they were exhausted.
150g of rice and 240 *ml* of water

Time	Fluctvation of total volume	Time	Fluctuation of total volume	Time	Fluctuation of total volume
5 min	1.29 *ml*	34 min	3.15 *ml*	1hr 2 min	1.24 *ml*
6	1.40	35	3.09	3	1.19
7	1.53	36	3.02	4	1.14
8	1.69	37	2.95	5	1.10
9	1.85	38	2.87	6	1.06
10	2.01	39	2.80	7	1.01
11	2.17	40	2.73	8	0.97
12	2.33	41	2.65	9	0.94
13	2.50	42	2.57	10	0.90
14	2.65	43	2.49	15	0.73
15	2.79	44	2.41	20	0.60
16	2.91	45	2.33	25	0.50
17	3.02	46	2.26	30	0.41
18	3.12	47	2.19	35	0.35
19	3.21	48	2.11	40	0.29
20	3.27	49	2.04	45	0.25
21	3.34	50	1.97	50	0.21
22	3.38	51	1.90	55	0.18
23	3.42	52	1.83		
24	3.44	53	1.76	2hr 00 min	0.16
25	3.44	54	1.69	30	0.06
26	3.44	55	1.63		
27	3.43	56	1.57	3hr 00 min	0.00
28	3.41	57	1.51	30	−0.03
29	3.38	58	1.45		
30	3.34	59	1.39	4hr 00 min	−0.04
31	3.31			40	−0.05
32	3.27	1hr 00 min	1.34		
33	3.21	1	1.29		

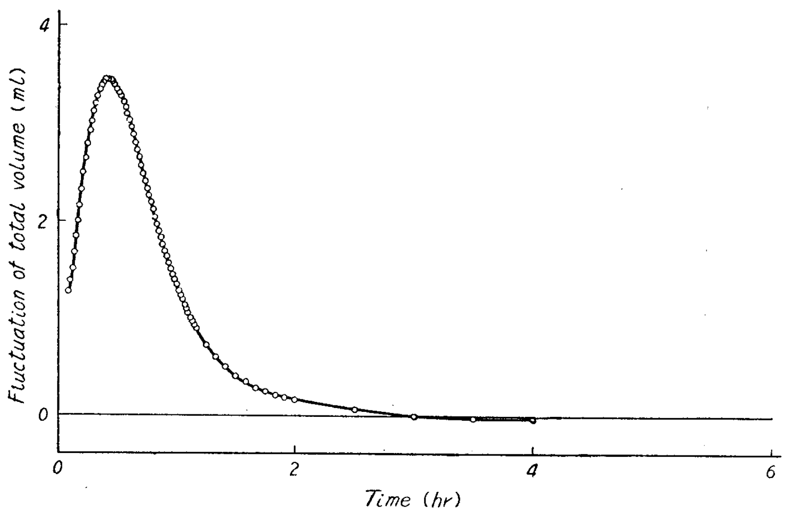

Fig. 6. The velocity curve of the fluctuation of total volume of the polished glutinous rice and water, after they were exhausted.

Table 5. Thefluctuation of the total volume of the polished SASASIGURE and water, before they were exhausted.
150 g of rice and 240 *ml* of water

Time	Fluctuation of total volume	Time	Fluctuation of total volume	Time	Fluctuation of total volume
3 min	0.94 *ml*	24 min	1.66 *ml*	50	0.20 *ml*
4	0.96	25	1.65		
5	0.99	26	1.64	2hr 00 min	0.15
6	1.04	27	1.63	30	0.05
7	1.05	28	1.61		
8	1.13	29	1.60	3hr 00 min	0.00
9	1.22	30	1.57	30	−0.04
10	1.30	35	1.47		
11	1.37	40	1.35	4hr 00 min	−0.06
12	1.43	45	1.22	30	−0.08
13	1.50	50	1.09		
14	1.54	55	0.95	5hr 00 min	−0.10
15	1.57			30	−0.12
16	1.60	1hr 00 min	0.84		
17	1.63	5	0.73	6hr 00 min	−0.14
18	1.64	10	0.64	30	−0.15
19	1.66	15	0.55		
20	1.67	20	0.48	7hr 00 min	−0.16
21	1.67	25	0.41	30	−0.20
22	1.67	30	0.35		
23	1.66	40	0.26	8hr 00 min	−0.19

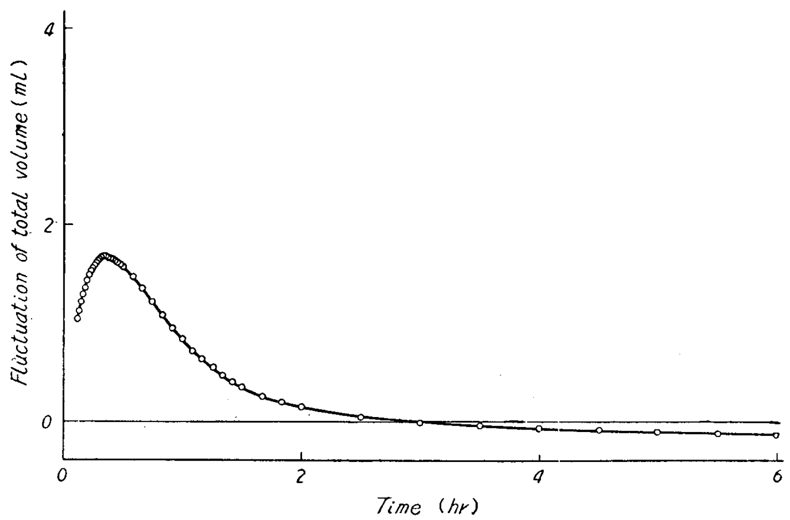

Fig. 7. The velocity curve of the fluctuation of total volume of the polished SASASIGURE (non-glutinous) and water.

Table 6. The fluctuation of the total volume of the unpolished SASASIGURE and water, after they were exhausted.
150 g of rice and 240 *ml* of water

Time	Fluctuation of total volume	Time	Fluctuation of total volume	Time	Fluctuation of total volume
2 min	0.88 *ml*	1hr 00 min	0.35 *ml*	8hr 00 min	−0.51 *ml*
3	0.79	10	0.33	30	−0.53
4	0.74	20	0.31		
5	0.69	30	0.28	9hr 00 min	−0.55
6	0.65	40	0.25	30	−0.57
7	0.62	50	0.22		
8	0.59			10hr 00 min	−0.59
9	0.57	2hr 00 min	0.19	30	−0.60
10	0.55	10	0.16		
11	0.53	20	0.13	11hr 00 min	−0.62
12	0.51	30	0.10	30	−0.63
13	0.50	40	0.06		
14	0.49	50	0.03	12hr 00 min	−0.64
16	0.47			30	−0.65
18	0.45	3hr 00 min	0.00		
20	0.43	30	−0.09	13hr 00 min	−0.66
22	0.43			30	−0.66
24	0.42	4hr 00 min	−0.16		
26	0.42	30	−0.23	14hr 00 min	−0.67
28	0.41			30	−0.68
30	0.40	5hr 00 min	−0.29		
32	0.40	30	−0.34		
34	0.40				
36	0.39	6hr 00 min	−0.38		
38	0.39	30	−0.42		
40	0.39				
50	0.37	7hr 00 min	−0.45		
		30	−0.48		

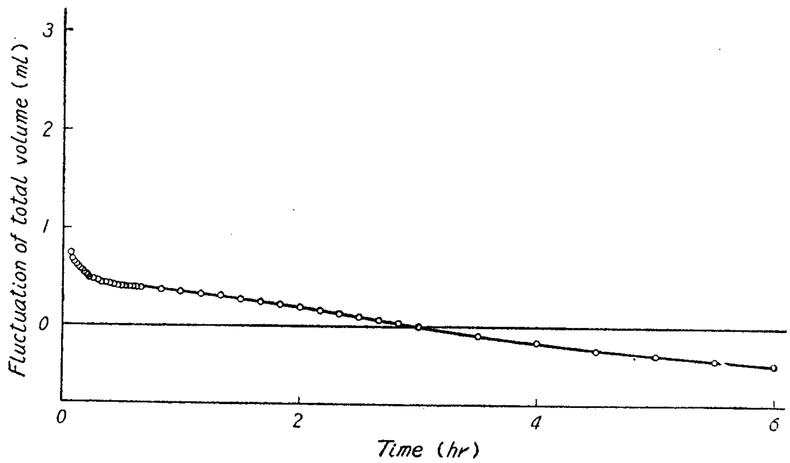

Fig. 8. The velocity curve of the fluctuation of total volume of the unpolished SASASIGURE and water, after they were exhausted.

Table 7. The fluctuation of the total volume of the unpolished MIYAKOGANE-MOTI and water, before they were exhausted.
150 g of rice and 240 *ml* of water

Time	Fluctuation of total volume	Time	Fluctuation of total volume	Time	Fluctuation of total volume
4 min	0.20 *ml*	38 min	0.33 *ml*	2hr 40 min	0.10 *ml*
5	0.19	39	0.34	50	0.06
6	0.23	40	0.35		
7	0.22	41	0.36	3hr 00 min	0.00
8	0.24	42	0.37	10	−0.06
9	0.23	43	0.38	20	−0.11
10	0.22	44	0.38	30	−0.16
11	0.21	45	0.39	40	−0.22
12	0.20	46	0.40	50	−0.27
13	0.20	47	0.41		
14	0.19	48	0.42	4hr 00 min	−0.32
15	0.19	49	0.42	10	−0.37
16	0.19	50	0.43	20	−0.41
17	0.19	51	0.43	30	−0.45
18	0.19	52	0.44	40	−0.50
19	0.19	53	0.44	50	−0.54
20	0.19	54	0.45		
21	0.19	55	0.45	5hr 00 min	−0.58
22	0.19	56	0.46	20	−0.66
23	0.20	57	0.46	40	−0.74
24	0.20	58	0.47		
25	0.21	59	0.47	6hr 00 min	−0.81
26	0.22			20	−0.87
27	0.23	1hr 00 min	0.47	40	−0.92
28	0.24	10	0.48		
29	0.25	20	0.47	7hr 00 min	−0.97
30	0.26	30	0.45	20	−1.01
31	0.26	40	0.41	40	−1.05
32	0.27	50	0.37		
33	0.28			8hr 00 min	−1.10
34	0.29	2hr 00 min	0.33		
35	0.30	10	0.28	9hr 00 min	−1.07
36	0.31	20	0.23		
37	0.32	30	0.18	10hr 00 min	−1.07

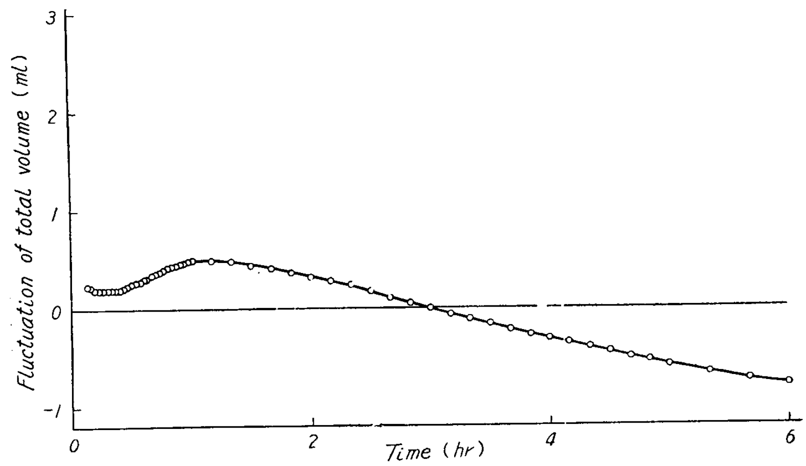

Fig. 9. The velocity curve of the fluctuation of total volume of the unpolished MIYAKOGANE-MOTI and water.

Table 8. The fluctuation of the total volume of the unpolished MIYAKOGANE-MOTI and water, after they were exhausted.
150g of rice and 240 *ml* of water

Time	Fluctuation of total volume	Time	Fluctuation of total volume	Time	Fluctuation of total volume
4 min	0.38 *ml*	1hr 00 min	0.31 *ml*	4hr 00 min	−0.32 *ml*
6	0.28	2	0.32	30	−0.45
8	0.21	4	0.33		
10	0.15	6	0.34	5hr 00 min	−0.58
12	0.10	8	0.35	30	−0.69
14	0.07	10	0.36		
16	0.04	12	0.37	6hr 00 min	−0.79
18	0.02	14	0.38	30	−0.87
20	0.01	16	0.38		
22	0.00	18	0.38	7hr 00 min	−0.95
24	0.00	20	0.39	30	−1.01
26	0.01	22	0.39		
28	0.02	24	0.39	8hr 00 min	−1.07
30	0.03	26	0.39	30	−1.13
32	0.04	28	0.39		
34	0.07	30	0.39	9hr 00 min	−1.17
36	0.08	40	0.38	30	−1.23
38	0.10	50	0.35		
40	0.12			10hr 00 min	−1.25
42	0.15	2hr 00 min	0.31	30	−1.29
44	0.17	10	0.27		
46	0.19	20	0.22	11hr 00 min	−1.32
48	0.21	30	0.17	30	−1.34
50	0.23	40	0.11		
52	0.25	50	0.06	12hr 00 min	−1.36
54	0.26			30	−1.35
56	0.28	3hr 00 min	0.00		
58	0.30	30	−0.17		

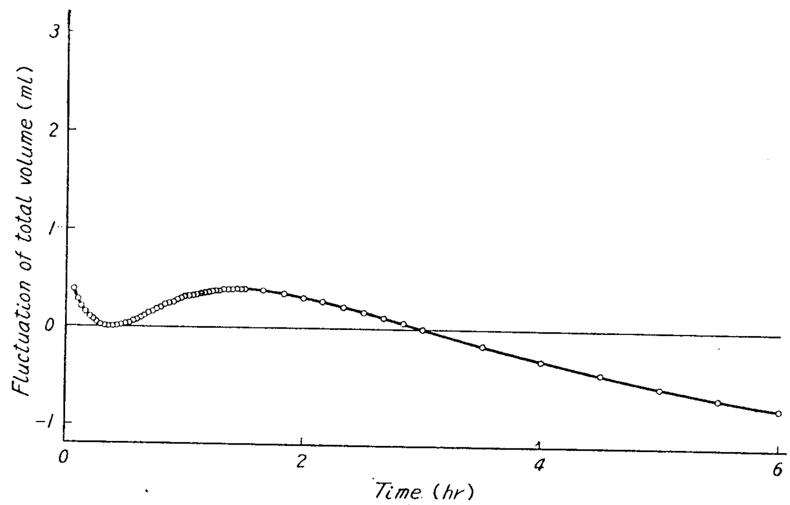

Fig. 10. The velocity curve of the fluctuatin of total volume of the unpolished MIYAKOGANE-MOTI and water, after they were exhausted.

at this time, it should be considered that the considerable increase of total volume, over 1 *ml* for 150 g of rice must come from some unknown cause, which will put the actual total volume decrease out of sight.

In this connection, the effects of the air held in the rice must be watched, but as shown in Fig. 4, after exhaustive experiment, the shape of the velocity curve of swelling has almost the same peak at 21 min after the swelling is started. As shown in Figs. 5 and 6, the curves of the polished glutinous rice shows little differences, and the abnormal phenomenon in question is more remarkable. Accordingly, this phenomenon is known that it has no relation with the varieties of rice. So the measurement was done with SASASIGURE (non-glutinous one) to ascertain this question. This sample is pure in its variety and it has been cultivated and harvested by the established methods at the Miyagi Agriculture Experiment Station.

The tendency shown in the observed values are, as shown in Fig. 7, almost the same as are observed in the sample other than SASASIGURE. The swelling velocity of unpolished SASASIGURE, and MIYAKOGANE-MOTI are shown in Figs. 8 and 9, and the increases of total volume are also found. So the values of unpolished SASASIGURE when it was measured before it was exhausted were unsatisfactory in their reappearance, and so the measurement was given up half way. But the swelling velocity of MIYAKOGANE-MOTI after it has been exhausted is higher when it is compared with the other, so the effect of their seed coat is clearly seen to be quite important. In comparison with the values of polished rices, it is very interesting to find the total volume decrease happen just after the starting of the swelling, and then the total volume increase follows, and then at last a decrease happens again. But in the case of SASASIGURE, the total volume decrease seems not to happen, but even then the velocity curve is abnormal in about 20 min after starting and continues so for 3 hr, and so it shows that the phenomena which takes place in this case is not the total volume decrease alone.

As aforesaid, these varieties of velocity curves are shown by two phenomena: the total volume decrease and its increase, which are taken place under various time, velocity and degree.

If it is so, what is the mechanism of this increase of volume? It is certain that this phenomenon has no connection with variety and polishing of rices, or evacuation. The fundamental cause of the phenomenon is yet to be found in the future.

Summary

The apparatus was constructed for the purpose of determining the velocity of swelling of rices by measuring the total volume of the sample and water, and thereby the swelling velocities of a few samples were measured.

The curves of velocity obtained are different from those of any substances ever studied; they are not simple.

The total volume increased in the beginning of the swelling, which is against common sence in physicochemistry. These abnormal phenomena will be derived from the causes which will bring the increase and the decrease of the total volume at the same time, but the fundamental cause must be left for in future study.

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References

1) Sair, L., W. R. Fetzer (1944). Ind. Eng. Chem., **36**, 316.
2) Sair, L., W. R. Fetzer (1944). Ibid. 205.
3) Katz, J.R., (1917). Kolloid Beihefte **9**, 70.
4) Yoshinaga, T., S. Kikkawa and S. Katsumata (1955). Seisan Kenkyu **7**, 304. (in Japanese)
5) Taffel, A., (1922). J. Chem. Soc., **121**, 1971.
6) Arisz, L., (1915). Kolloid Beihefte **7**, 49.
7) Hogan, J. T. and R. W. Plank (1958). Cereal Chem., **35**, 469.
8) Campbell, J. D. (1958). Ibid. 47.
9) Samejima, J. (1948). Kositugaku (Colloid chemistry) p. 556, Syokabo, Tokyo. (in Japanese)